Cognitive Design Factors for Mixed Reality Environments

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1. Introduction

Augmented reality is an example of a mixed reality environment – it includes elements of the real world and virtual elements that are added. Although the technology exists to support a range of augmented reality applications, there is a need to develop an understanding of appropriate design methods. For example, what is the right balance of virtual versus real elements? What role should the virtual elements play with regard to the real scene elements – annotation and commentary, selection, extension, or independant additions? In the context of mobile augmented reality, we may extend these questions. What is the role of virtual intrusions that emphasize allocentric versus egocentric point of view? Should we be emphasizing one over the other? What is the appropriate mix of augmented reality in different sensory modes, for example, sound, sight, smell, touch?

While these and other questions may ultimately depend on the specific applications supported by the augmented reality environments, there is still a need to situate these applications in relation to a general understanding of augmented reality and other mixed reality immersive environments.

In research undertaken on mixed environments in application areas ranging from aiding the handicapped to developing new approaches for stage performance or museum exhibitions, a new, cognitive approach to these design problems has been formulated. Although the new framework is targeted first for immersive mixed reality environments in the performing arts, part of the framework is of direct relevance to more general mixed reality environments, including augmented reality. In this paper, the broad outlines of the full approach are provided, with a particular focus on the elements most relevant to the mobile augmented reality environment. Although no ultimate answer is provided to the question of finding an appropriate design framework, several avenues of exploration are provided.

2. A cognitive framework for design

The general approach adopted here is that immersive mixed reality environments provide the opportunity to enable total learning, that is, learning that solicits all of our sensory modalities. For decades, centuries even, we have isolated learning to language-based or visual modes, or both, with a distinct suppression of body-based learning. Modern cognitive theory is telling us something rather different. Environmental learning is most effective when the body is engaged as well as the mind. Human beings need all their senses to be activated, not just their language-processing and visual brain regions. The growing use of immersive mixed reality environments encourages such learning, and effective design of mixed reality environments such as augmented reality should capitalize in these factors.

The theoretical framework proposed (Edwards and Bourbeau, 2006b) follows from this principle. It is constructed in terms of three levels, related to three different levels of cognitive functionality and neurological activation. These are the level of activation of single, specialized brain regions (what might also be called the "perceptual level", the level of activation of large networks of brain functionality (also called the "representation level"), and the activation of brain regions devoted to interactive, usually social phenomena (the "interaction level").

2.1 Design at the perceptual level

We identify two learning contexts, depending on whether the immersive environment serves essentially as an on-line source of information or as an immersive cultural experience. For the first case, at the perceptual level of cognitive functionality, we are more likely to be interested in extending direct perception by providing additional, information-rich annotations or extensions of perceived objects or relations. In the second case, our focus will also be on enhancing the effectiveness of mental imagery in the immersive environment.

2.2 Design at the representational level

At the intermediate level of cognitive function, networks of neural activity are engaged in tasks such as language production, attentive structuring, situational awareness and identity maintenance, hence towards different forms of representation. Each of these tasks has been shown to be important in supporting the understanding of immersive performance and it is likely that they are relevant to a broad range of immersive experiences.

2.2.1 Language production

Although language production may take many different forms, one aspect of language production that has been studied in the context of mixed reality environments is the presence and use of image schemata. Image schemata are perceptual invariants related to human manipulation of the environment, which have been encoded in language (Lakoff, 1987; Johnson, 1982). Some fifty or more image schemata have been identified by linguists – they are found in all languages and cultures. Image schemata include concepts such as CONDUIT, CONTAINER, SURFACE, FORCE, REPULSION, etc. People spontaneous and intuitively identify image schemata in all sensory modalities continuously and automatically. However, this process is almost entirely unconscious. Work with the performing arts has shown how the conscious emphasis on certain image schemata during the design process can intensity the experience delivered to the user, and may also serve to strengthen the reception of certain messages on the part of the user (Edwards and Bourbeau, 2006a). Hence an effective use of augmented reality enhancements to enhance learning would be to emphasize one image schema over another. Hence, the introduction of graphical elements or spatial overviews that emphasize a particular schema may be used to draw attention to certain aspects of the environment, or sound-based image schema may be used to comment on aspects of the visual environment. For example, a visual AR device may emphasize the way an environment constrains and contains the elements present (CONTAINER), or it may instead focus on how information or free agents may move through the environment (CONDUIT). Likewise, sound cues may emphasize CENTRE over PERIPHERY or vice versa. These clues assist in the process of spatial or structural interpretation.

2.2.2 Attentive structuring

Attentive processing of our environment is limited by the carrying capacity of short term, what is often called working memory. Working memory may hold no more than seven items of information for a typical individual. In order to hold more information, the latter must be « chunked » or grouped together. Chunking takes up additional memory resources, but less than those required for holding the pieces that make up each chunk. When people perceive an environment in an attentive way, such as in order to communicate with another person, to update mental models of the environment, and so on, they will spontaneously engage in a process of segmentation and chunking in order to hold in memory a representation of the environment. This process is rendered more or less difficult by the nature of the information presented. Furthermore, a similar process of segmentation and chunking occurs for spatial information (scene structure), temporal information (event structure), and also thematic information (associative or semantic structure).

Augmented reality may be used to modify the chunking processes carried out by the viewer. Hence, particular sets of objects may be grouped to emphasize their structural relationships, for example, using markers, filling in gaps or creating gaps where there are none. Furthermore, people structure information in such a way that it is aligned across different scales of aggregation or chunking (Tversky et al, 2005). Augmented reality devices may facilitate or hinder this spontaneous multiscale chunking. Also, virtual enhancements may be used to mark changes from one event to another. These changes are important to the way we understand the temporal evolution of the world around us. Marking these changes helps structure events over time. Such annotations of the world are relatively easy to develop since they do not require exact matching of virtual to real scene elements, but may substantially enhance interpretative learning.

2.2.3 Identity construction and maintenance and situational awareness

The third representational cognitive function is that involving identity construction and maintenance (Edwards and Dornic, 2006), including situational awareness. Identity maintenance has been recognized as one of the main functions played by enabling technologies in everyday life. Identity is defined as a system of values, representations, needs and emotions that have a common history, an actualizing present, and are future-directed. Mixed reality environments may challenge certain aspects of identity, and care should be taken to support identity maintenance when appropriate. Although identity maintenance is about « who we are », part of it includes « where one is », hence one's situational awareness. Knowing where one is has been identified as the first question usually asked by people when in an unfamiliar environment. Both identity maintenance and situational awareness affect point of view in the design of mixed reality environments. For example, emphasizing the egocentric point of view of the user is an important aspect of identity maintenance and helps personalize the experience and enhance situational awareness.

2.3 Design at the interaction level

The top level is organized around the recognition of interactive entities we call "manifestations", whether these be either presence or place. The notion of « presence » has been widely discussed in the literature. The notion of « place » has been less widely discussed but is no less important. For both concepts, we are concerned with a hybrid definition – a sense of presence that is formed by elements contributed both from reality and from virtual enhancements, and the same for a sense of place (MacIntyre *et al*., 2004), and with the fact that these are interactive complexities that engage the user. Augmented reality, ultimately, is concerned with designing hybrid presences and places that, when combined, form an interactive experience that goes beyond what a person would ordinarily encounter – whether his or her interest is concerned with new forms of information or new learning contexts. This is as true of applications, for example, to assist municipal operations with underground conduits or to provide an indication of property boundaries in judicial disputes, as it is for providing new museum or performance experiences. These practical examples of augmented reality applications all repose on the idea that « place » is extended from its real world form to include additional, virtual elements. Applications in cultural domains such as museology or the performing arts emphasize the importance of presence, which can either involve the sense of being in contact with an environment, or the sense that an agency is actively engaging with us.

3. Discussion and conclusions

The ability to modify the way environments are perceived, represented and enter into interaction with users constitutes a profound change in design paradigms. As long as individuals are only watching the real world, the only way to modify the message being delivered is by modifying the design of the real world. This is possible in performance and via architectural means, but the scope of such changes is limited. With the introduction of virtual elements into the perceptual environment, however, the mixed environment is itself a form of message and there is a need to understand how such messages affect learning and information processing in humans, and to develop design methods that take into account such factors. Image schemas, which are part of the hidden, automatically processed perceptual landscape, then become powerful tools for molding elements of the experience delivered to the user. Likewise, marking events over time or spatial groups should be a part of any enhancement strategy, or at least an understanding of how additional elements introduced into a scene may modify such perception should be present. The experience delivered must help to situate the user, especially in a mobile context, but the experience may also to provide functionality for broader aspects of identity maintenance and not just situational awareness. Finally, the ability to construct hybrid virtual/real interactive agencies such as presences or places, constitutes the top-level functionality which one should strive to achieve, and the other levels of design must be corralled to support these developments. In this way, total learning environments may be achieved through augmented reality.

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